The mesolithic-neolithic transition and the chronology of the 'elm decline'

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The Mesolithic-Neolithic transition and the chronology of the 'elm decline'; a case study from Yorkshire and Humberside, United Kingdom

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Abstract. The Neolithic in Britain saw the first appearance of domestic plant and animal resources, pottery, polished stone axes, monuments and new house structures. With the introduction of domesticates and associated subsistence strategies, the Neolithic represents a significant change in human-environment interaction. Other changes have been observed in the palynological record of Britain in the early fourth millennium cal BC, including the elm decline, and archaeologists and palaeobotanists have long discussed the degree of human involvement in this. This paper presents Bayesian statistical analysis of the elm decline in the east of Yorkshire and Humberside and key sites in west Yorkshire, and evidence for the last hunter-gatherer Mesolithic material culture and the first Neolithic material culture record. This region is critical because it is the only area of Britain and Ireland where we have robust and accurate published estimates for the timing of the latest Mesolithic activity and timing for the earliest Neolithic activity. Unpacking this perceived chronological correlation between the elm decline and the start of the Neolithic is critical to understanding the scale of human-environment at this time, and the nature of the first Neolithic societies in Britain.

Keywords

Elm decline

Bayesian

Neolithic

Mesolithic

Human-environment interaction

Introduction

The mid-Holocene 'elm decline' recorded in many pollen diagrams from north-west Europe has long been the subject of palaeoecological and archaeological debate (Huntley and Birks 1983; Edwards and Hirons 1984; Hirons and Edwards 1986; Parker et al. 2002). The 'elm decline' may be regarded as a complex palaeoenvironmental 'event', often with evidence for a first major reduction in elm pollen (i.e. the start of a sustained fall in elm pollen frequencies), and sometimes a second sustained reduction in elm pollen frequencies following the recovery of elm from the first decline in the same sample sequences (Hirons and Edwards 1986, 138).

The link between the elm decline and the start of farming has long been present in the literature (e.g. Troels-Smith 1960), with the elm decline appearing "...to be linked directly or indirectly to the onset of agriculture and land clearance..." (Whitehouse et al. 2014, 185). Other factors contributing to the elm decline have been suggested, including a climatic component or pathogen response (Parker et al. 2002). Batchelor et al. (2014) have recently demonstrated a relatively early trend in declines in elm pollen in southern Britain suggesting a complex, potentially multi-factor, site-specific process.

The timing — and critically the duration — of this 'event' has been discussed with reference to how synchronous or time transgressive the decline was across Britain (Smith and Pilcher 1973; Huntley and Birks 1983; Turner et al. 1993; Parker et al. 2002; Bronk Ramsey and Lee 2013; Whitehouse et al. 2014). It has been argued that "...the elm decline across the British Isles was a catastrophic, uniform phased event..." (Parker et al. 2002, 28; our emphasis), whilst the same authors also state "...the elm decline must have occurred between 6347 and 5281 cal. yr BP at 95% of the sites, a time span of 1066 years" (Parker et al. 2002, 28; cf. Whitehouse et al. 2014). As Lee (2012, 181) noted of the chronologies for the elm decline from Britain and Ireland as a whole "...the resolution of the radiocarbon determination is low, and the majority of determinations were from peat samples, which are themselves problematic to date..." meaning that our understanding both locally, regionally and across Ireland and the British Isles as a whole is limited.

The relationship between the elm decline and the cultural changes associated with the Mesolithic-Neolithic transition has recently taken on new resonance given the precision afford by Bayesian analyses for the timing and tempo of the appearance of Neolithic material culture and practices in Britain and Ireland (Whittle et al. 2011; Whitehouse et al. 2014). Chronological analysis of the timing of the elm decline is essential in order to address how local Neolithic lifeways and human-environment interactions might have contributed to local environmental changes. Recent evidence for time transgressive regional aspects of the first appearances of Neolithic material culture and changes in the rate at which Neolithic practices appear (Whittle et al. 2011), mean that understanding spatial variability and regional patterns in evidence for the elm decline take on critical importance. Research by Lee (2012, 180) applying a Bayesian approach to the elm decline across Britain and Ireland suggested that the "...elm decline in England and Scotland started before [the] elm decline in Ireland and Wales, and [the] elm decline in Scotland ended later than all of the other regions...". The time transgressive nature of the elm decline is important if we are to understand potentially complex human-environment interactions, and to attempt to explore other potential contributions to the decline such as disease or climate change (see Parker et al. 2002).

Contributions of people engaged with late Mesolithic lifeways to the appearance of Neolithic practices and material culture are fiercely debated (e.g. Thomas 2013; Sheridan 2011), and these lifeways may have had implications for the elm decline. New chronological understandings for late Mesolithic activity in Yorkshire and Humberside (Griffiths 2014a) allow us to compare these with the appearance of early Neolithic lifeways (Griffiths 2014b) and regional evidence for the elm decline, and to address the complex of Neolithic and Mesolithic human-environmental interactions (cf. Warren et al. 2014).

As we currently understand it, Britain and Ireland probably do not have evidence for foragers engaged with otherwise ‘Neolithic’ practices such as the use of pottery by hunter gatherers seen in parts of North West Europe (e.g. Fischer and Kristiansen 2002). In Yorkshire and Humberside however, we have evidence for chronological overlap of Mesolithic and Neolithic populations, and potential for subtler, regional processes of change. People here continue using Mesolithic material culture in the uplands of the Pennines after the appearance of the first monuments, domesticates, pottery and polished stone axes on the low land valleys and the uplands of the Yorkshire Wolds (Griffiths 2014a; b), with the latest use of Mesolithic rod microliths in the Pennine uplands occurring in *3960–3730 cal BC* (*95% probable*; Griffiths 2014a), and the Neolithic first evident in *3920–3720 cal BC* (*95% probable*; Griffiths 2014b).

Yorkshire and Humberside additionally presents an ideal study area for the context of human-environment interaction across the Mesolithic-Neolithic transition, as parts of the region are amongst the most intensively investigated of the United Kingdom in terms of detailed palaeoenvironmental research. In particular, North Gill on the North York Moors (fig. 1), has been the focus of highly detailed and influential palynological studies over the last four decades (e.g. Simmons 1969; 2003; Simmons and Cundill 1974; Simmons and Innes 1981; 1987; 1988a; b; c; d; 1996a; b; c; d; Simmons et al. 1989; Innes and Blackford 2003; Turner et al. 1993; Innes et al. 2013; Albert and Innes 2015). In this paper we review the available evidence for the elm decline in Yorkshire and Humberside, producing new chronological estimates for the palaynological signals for this event across the region, and compare these to new evidence for the end of the Mesolithic and start of the Neolithic in the region.

Method

Site selection

Eighteen palaeoenvironmental sequences from the main study region with radiocarbon dates predating 3300 cal BC were identified across Lincolnshire, through Humberside and the North Yorkshire Moors (fig. 1). The sequences were recovered from a range of depositional environments including blanket peat, intertidal and floodplain peats. Some intensively investigated sites have been excluded from analysis, for example the previous chronological modeling of pollen records from the lowland raised mires of Hatfield and Thorne Moors, which demonstrated that declines in elm can be assigned to broader clearance of woodland during the Bronze Age (Chapman and Gearey 2013). To the west of the main study region a series of complementary sequences was identified for comparison. These were Gransmoor (Beckett 1975), White Moss and Eshton Tarn (Bartley et al. 1990), Rishworth Moor (Bartley 1975), Robinson’s Moss (Tallis and Switsur 1990) and Soyland Moor (Williams 1985). These sequences were selected to provide upland contrasts with the predominantly lowland Yorkshire and Humberside examples, and to provide context for the important South Pennine Mesolithic landscape around March Hill (Griffiths 2014a).

Fig. 1. Palaeoenvironmental study sites from the region. Selected late Mesolithic and early Neolithic sites with robust radiocarbon chronologies (Griffiths 2014a and b) are also shown. Analyses are detailed below and in the supplementary material.

The majority of the dated samples comprise slices of ‘peat’ or other sediment (table 1 and supplementary material). Radiocarbon measurements on ‘peat’ can be accomplished by dating different chemical fractions, most commonly the 'humin' (the alkali and acid insoluble material) and 'humic' acid fractions (the alkali soluble and acid insoluble material), or macrofossils extracted from peat samples. Generally shortlife, single entity, terrestrial plant macrofossils, which might have grown in situ at the time of the peat formation are deemed preferable (Bayliss et al. 2008; cf. Griffiths et al. 2015). As we shall note below, the different natures of the dated materials adds another issue in terms of providing accurate estimates for variability of the timing of the elm decline in the region.

Bayesian modelling

For the majority of the sites (see table 2, fig. 2 and supplementary material), models of radiocarbon dates from pollen sequences that include evidence for the elm decline have been produced using the program OxCal v4.1 (Bronk Ramsey 1995; 1998; 2008; 2009) and IntCal13 (Reimer et al. 2013). For each of these sequences a model was constructed that assumed that the sediment accumulation process is an inherently random or a 'Poisson' process (the P_Sequence function in OxCal v4; Bronk Ramsey 2008; cf. Blaauw and Christen 2005). Our models make allowances for changing sediment accumulation rates, by including details of the interfaces between lithological units where these were specified in the original publications (using the OxCal Boundary parameter, developing the approach of Lee 2012). Deposit models were implemented to allow for flexibility in the estimation of the formation of the sediment over the depth of the core, by averaging values of k (the rigidity of the model) between 0.01 and 100 cm^{-1}, which should provide a robust model for any sedimentary sequence (Bronk Ramsey and Lee 2013, 723). The interpolation rate was set to 1. By defining the lithological units using Boundary parameters, and with the relatively limited data per unit, the effect in practice in many sequences is that the deposition rate within different units will appear fairly constant. An example of the deposition modeling is shown in fig. 2 with other models presented in the supplementary material, the modeling approach is described in the text, and selected output ranges for the elm decline are given in table 2.

Fig. 2. An example of the type of deposition model produced during this analysis using the results from Bonfield Gill. As with the other modeling approaches here the results have been analyzed using the deposition notation P_Sequence("Bonfield Gill",1,1,U(-2,2) ...

For 'humin' and 'humic' acid measurements from the same horizons statistically consistent results were combined (Ward and Wilson 1979). Where there were age inversions or samples from the same depth were not statistically consistent, formal outlier analysis was used to identify radiocarbon results that were removed from the models (Bronk Ramsey 2009, 1024). Results not included as active likelihoods are indicated by the "?" sign in the model figures (fig. 2 and supplementary material). Estimates for the timing of the elm declines in each sequence have been produced using the Date parameter at the appropriate depths quoted in the original publication reports, or depths suggested in this analysis (see table 1 and 3).

Results

From the region, several sites reviewed did not produce clear evidence for 'elm declines' and are not discussed further (see supplementary material). Twenty-nine sites produced evidence for the elm decline with associated radiocarbon dates, though as we shall see in discussion below, there is considerable variation in the timing of these events.

The critical factor in the estimate for the timing of elm decline signals in most of these cases is not the modeling approach employed, but the nature of the dated samples and their associations with the palaeoenvironmental events of interest (see discussion below). An important aspect of this is how and where the original analysts identified the elm decline in a given sequence, which is in large part dependent on the sampling interval employed (table 3). Comparison of different palynological records can be complicated by the fact that analysts may adopt different approaches to producing pollen sums (see also Parker et al. 2002, 3). For the sites discussed in this paper, the pollen summing approach varies from total land pollen (%TLP), to percentage total arboreal pollen (%AP), to total land pollen minus *Corylus, Alnus* and *Betula* (at the North Gill sites; see table 3). With the exception of two sites, the elm decline is comparatively clear in all the records, although there is some variation in terms of the apparent rapidity of the event (see discussion below).

For the sites of Bluewath Beck and Gilderson Marr the elm decline events are not estimated using deposit models, as in both sequences the elm decline pollen signals were not bracketed by radiocarbon measurements. For Bluewath Beck the measurement Wk-12078 (5879±40 BP) provides a terminus post quem for the elm decline signal, which is of limited use in unpicking the timing of the elm decline at this site. For Rishworth Moor (Gak-2822), Eshton Tarn (Birm-663), Gransmoor (SRR-229) single results estimate the elm decline at each site. A single result from Langlands Farm (GrA-24660) provides a terminus post quem for the elm decline at this location. From Sharow Mire, a result (SUERC-8881) from the base of the sequence provides a terminus ante quem for the elm decline at this sample location; this result is inconsistent with another from this sample depth (SUERC-8885) and the robustness of either of these results' association with the elm decline is unclear.

From the Nosterfield sites of F45 and SH1, the models published in Bridgland et al. (2011) were adapted. For F45, the three results recovered from the lowest part of the sequence have not been included as actively likelihoods in the model (Beta-143456; GrA-25355; OxA-13530); these include very early Holocene results which do not concur with the palynological evidence that the start of the sequence post dates the elm decline, and a result (GrA-25355) which is too early for the position in the sequence. An estimate for the start of the formation of deposits in the sequence provides a terminus ante quem for an elm decline here. The model for the Nosterfield SH1 sequence does not include OxA-13225 as an active likelihood as this result is too old for its position in the sequence.

The results from the North Gill sample site NG1A presented multiple modeling solutions; in this case the statistically consistent (T'=0.0; T'5%=3.8; df=1) radiocarbon results from the elm decline deposit are used to estimate its timing (fig. 3). Similarly, the calibrated radiocarbon results from the elm decline horizons from Routh Quarry, Gilderson Marr, Lambwath Mere and The Bog at Roos are included in fig. 3. The results from Lambwath Mere, Gilderson Marr, and the Bog at Roos produced multiple potential modeling options, with these sequences producing measurements with multiple radiocarbon age inversions, and too few measurements to be able to suggest which results were best used to constrain the timing of the elm decline. The results estimating these events were included in the discussion presented below. The remaining sites (Soyland D, Soyland C, Harwood Dale, North Gill 4, Esklets 1, Newby Wiske 1, White Moss, Robinson's Moss, Fen Bogs, Bonfield Gill, North Gill 9, North Gill 7, North Gill 5b and North Gill 6) were all modeled as outlined in fig. 2 (and see supplementary).

Fig. 3. Estimates from the elm decline for all the sequences that modeled, and calibrated radiocarbon dates from Rishworth Moor, North Gill ~~NG~~A1, Routh Quarry, Gilderson Marr, Roos, Bluewath Beck, Gransmoor, Sharow Mires (providing a terminus ante quem for the decline), Lambwath Mere and Langlands Farm (providing a terminus post quem for the decline).

Of the results shown in fig. 3, it is apparent that only some have produced middle Holocene chronologies. The nature of the early elm declines are also variable. For example, at North Gill sample site North Gill 9 two ‘elm declines’ were recorded in the pollen record, while at Esklets 1, a ‘temporary elm decline’ was noted by Albert and Innes (2015) though this appears to be associated with a hiatus in peat accumulation. We shall return to these points in the discussion below.

From the evidence we have assembled here, elm declines are associated with radiocarbon measurements from the mid fifth millennium to the first millennium cal BC. The total duration of activity represented by these measurements is estimated in fig. 4 as *2900-3620 years* (*95% probability*; or *2990-3320 years 68% probability*; *Duration elm decline*). The temporal variability of ‘the elm decline’ emphasizes the importance of how palaeoenvironmental events are defined. In palaeoenvironmental contexts, the ‘elm decline’ can be defined both as a signal from proxy data and chronologically as an event —which we can find in the archaeological record — at or close to the Mesolithic-Neolithic transition. If an event has both chronological and palaeoenvironmental definition, we begin to reify our data with our archaeological assumptions. In this case, some scientific chronological data become regarded as ‘chronologically acceptable’ and some as not. These approaches to data are especially important when we begin to look at processes, both in terms of local process of vegetation change and in terms of human-environment interaction. This is especially so if we seek to explore the potential for correlation with cultural practices which might be equally difficult to define (fig.5).

Fig. 4. The total duration of activity associated with ‘elm decline events’ shown in fig. 3.

Fig. 5. Detail of the estimates for the earlier prehistoric elm decline and estimates for the start of the Neolithic in Yorkshire and Humberside, and the latest Mesolithic activity in this part of the world.

The elm decline is traditionally thought to have been associated with Neolithic activity in Britain, or to have occurred after the start of Neolithic activity (Whitehouse et al. 2014). In this region, both the elm declines represented in North Gill 9 and the elm declines sampled in Nosterfield SH1, Soyland D, Rishworth Moor, Langlands Farm, Gilderson Marr, Harwood Dale, Roos, North Gill 4, Esklets 1, and probably Lambwath Mere and the start of the decline at Newby Wiske occurred before the end of the Mesolithic in the region (parameter *M_N* in fig. 5; calculated and discussed in Griffiths 2014a and b) and before the start of the earliest available evidence for the start of the Neolithic in the region (parameter *Start_Y_H_early_Neolithic* in fig. 5; calculated and discussed in Griffiths 2014a and b). In contrast for example, it is *90% probable* that the start of the Neolithic in Yorkshire and Humberside (*Start_Y_H_early_Neolithic*) occurred before the elm decline recorded at Bonfield Gill (*Bonfield Gill elm decline*; fig. 5). Other elm declines occurring after the start of the Neolithic include those at Esklets 4, Fen Bogs, North Gill

1A, North Gill 7, North Gill 5b and Soyland Moor C.

These results demonstrate that the elm decline across Yorkshire and Humberside cannot be regarded as rapid or synchronous (cf. Parker et al. 2002) and is not necessarily closely associated with the Mesolithic-Neolithic transition in the region. This applies even if the later elm declines are excluded from discussion — there is evidence for different estimates for elm declines across the intensively studied location of North Gill for example. The calibrated radiocarbon dates and posterior density estimates from the North Gill sites indicate the elm decline took place over *2540-2820 years* (*95% probable*; or *2600-2740 years 68% probable*), across a sample area of only several hundred meters; our evidence for the timing of this 'event' shows considerable variability even here. Of the North Gill sequences, North Gill 1A, North Gill 5b, and North Gill 7 have produced very similar estimates for the elm decline (see table 2). In classic palynological terms, this could represent the second sustained reduction in elm pollen frequencies following the recovery of elm percentages from a first elm decline (Hirons and Edwards 1986, 138), or this could derive from a hiatus in deposit formation for which there is not evidence in the stratigraphy or pollen proxies. There remain however very different estimates from North Gill 9 and North Gill 4 that should be interrogated in any discussion of the elm decline (table 1); developments in precision mean it is not simply enough to suggest these results are contemporaneous or 'noise'. These data may inform on process. An important aspect of the studies at North Gill is the high-resolution pollen-sampling interval adopted (table 3), which means that the elm decline can be precisely located. However, it can also be noted that the expression or form of the decline varies, with the reduction in *Ulmus* at North Gill abrupt (over 1cm sample interval) at North Gill 1A, North Gill 4, North Gill 6 and North Gill 9 to rather less so (resolved over 4-6cm sample intervals) at North Gill 5b, North Gill 7, and North Gill 9.

The original analysts at North Gill concluded that this spatial and chronological variation could be attributed to each location having a "...different management history between 9000-6000 BP..." with Mesolithic impacts (burning, lopping of trees) and climatic deterioration affecting the quality of the local soils and hence the ability of elm to regenerate after each impact 'event' (Turner et al. 1993, 646). Disease is implicated as a causal factor in this scenario but it is suggested the reason that adjacent sites (for example, sites North Gill 7 and 9 are c. 50m apart) do not record synchronous declines is that those pollen sequences were located close to soils with optimal nutrient status supporting elm populations that were better able to recover following the initial impacts of disease. In other words, the elm decline at North Gill is not strictly regarded as asynchronous and must be understood as a hyper-local process, with diseased trees rapidly replaced at certain locations. Hence the impact of this 'process' is essentially 'palynologically invisible' during the initial onset. In this scenario, the later declines demonstrate the subsequent, palynologically identifiable, impact on local elm populations.

An associated aspect of this hypothesis is the assumption that for such apparently divergent vegetation histories, the relevant source area of pollen (RSAP; Sugita 1994) for the sampling locations must have been very small. In the case of those sequences which are relatively close to each other (North Gill 8 is less than 40m north of North Gill 1A) but show chronologically disparate declines, this would imply the RSAP for the sampling sites must have been at the very lowest end of the estimates for forest hollows (c. 2m diameter) calculated by Sugita (1994). This hypothesis could be usefully tested further through palynological modeling approaches (e.g. Caseldine and Fyfe 2006).

However, further investigation may simply lead to evidence for greater complexity rather than greater clarity, in which case pollen taphonomic considerations may be contributing to this picture, especially in the case of multiple sequences sampled at very fine (1mm) intervals. Following the conclusions of the original analysts and the data presented in this paper, if the North Gill radiocarbon estimates associated with elm decline signals are robust, then it would appear that the elm decline on the North York Moors a highly complex 'event' occurred effectively on the microscale, with healthy or regenerating elms co-existing alongside areas of dead or dying elms. Such a picture is concurrent with causal mechanisms which include interaction between a disease vector, localized edaphic conditions and human impact. In this model an 'elm decline' is only recognizable in the proxies once some sort of 'palynological tipping point' is passed when the greater majority of elm trees within a given catchment were affected to an extent sufficient to produce a clear palynological signal (Turner et al. 1993, 646). In this scenario, it is possible that early, spatially restricted declines in elm would be invisible in any sequence with a relatively large RSAP. Under these conditions, the 'elm decline' could theoretically have begun earlier than apparently recorded in a given sequence, with associated implications for the identification of the timing and thus the underlying cause(s) of the decline. If we propose this as hypothesis for North Gill then we must also accept that these issues identifying the start of the elm decline could exist in other similar locations.

A further range of possibilities exists, including that some of the radiocarbon measurements are not accurate estimates for the date of the elm decline in the parent contexts (cf. Brock et al. 2011). It is possible, given the relatively limited numbers of radiocarbon dates from each North Gill sequence (and especially the inconsistency of the North Gill 4 sequence), that those from North Gill 4 and 9 are not robust estimates for the elm decline at these levels. If we accept that the similarity between the estimates from North Gill samples NG4, NG5b and NG7 represent the sustained reduction (or 'elm decline proper'), and we regard this as a local 'event' we can combine the posteriors from these sites to provide what may be the most robust estimate for the elm decline here (fig. 6), with the event estimated to have taken place in *3510-3420 cal BC* (*76% probability*) or *3380-3350 cal BC* (*19% probability*).

For sequences away from North Gill, the sampling interval — and thus the identification of the elm decline depth — adopted in the different studies could have implications for our understandings (see table 3). This may be the case for the sequences with comparatively wide sampling intervals as at Harwood Dale and Fen Bogs, where the timing of the decline could be resolved earlier. Given the relatively low values for *Ulmus* in the Routh Quarry sequence, it is possible that an earlier prehistoric decline at this site falls between the sampling interval (8cm). At other sides, aside from Esklets 4 (where the decline signal is very subdued), the reductions in *Ulmus* regarded as the 'decline' event are pronounced and recorded across sampling intervals of a maximum of 5 cm (Rishworth) but generally no more than 2cm, and sampling interval seems less likely to contribute to issues with the dating of the decline.

Beyond the specifics of the timing of the appearance or disappearance of different environmental proxies, the evidence from this case study concerning how we approach palaeoenvironmental events has more significant implications. Our interpretation of what the elm decline is — at its most extreme whether we conceive of this signal as 'event' or 'process' — has implications for how we interpret the available data and the range of possible causal processes we are willing to entertain. If we define the elm decline as an event with the same chronological signature in a determined study area, then we exclude data that are by this definition ‘noisy’. However these data might actually be telling us something important about the inappropriateness of our approaches, they might in fact be indicative of a complex process, or at least a process with palaeoenvironmental proxies with complex, poorly understood taphonomies. This then has implications for our causal narratives and our willingness to move between the specific and the general, and it is directly impacted by the scale of analytical approach taken.

Fig. 6. A combined estimate for the elm decline evidenced in North Gill cores NG4, NG5b and NG7. This approach excludes much earlier estimates from the North Gill landscape, and we cannot be exactly certain why these variable earlier signatures were detected over such a small landscape. The radiocarbon chronology and taphonomy of the proxies could be contributing to these earlier signals.

Discussion

Palynological conclusions

In this paper we have analyzed the radiocarbon chronologies associated with the elm decline in palynological records from Yorkshire and Humberside. In order to identify possible causes of this ‘event’ and to establish possible relationships with human activity as demonstrated by the archaeological record (e.g. Innes et al. 2013), we require robust chronological data. In all palaeoenvironmental research, an understanding of the taphonomic processes that resulted in the formation of assemblages that we analyze is essential. In the case of every elm decline — or any other palynological ‘event’ — we need to interrogate our proxies, to determine what they actually mean in terms of environmental reconstruction and the archaeology of people. It is only when we have rigorously examined our proxies in this way that we can begin to talk about processes, or the nature of different elm declines (cf. Smith and Pilcher 1973 on ‘rational limit’ and ‘empirical limit’; Hirons and Edwards 1986 on definition of the elm decline). The importance of increased precision that Bayesian modeling allows, should include an unpicking simplistic causal narratives resulting from chronologies which suck in or smear anthropogenic and palaeoenvironmental events (cf. Baillie 1991).

Without critically thinking about what our proxies mean, and what our analytical terms and scales impose on our data there is a real danger that palaeoenvironmental events become reified from concepts into things that are identifiable in the archaeological record. In such cases analysis can become focused on identifiable concepts rather than the specificity of palaeoenvironmental conditions at different study sites. In this case, palaeoenvironmental events can take on ‘mythic’ properties, where the abstraction from evidence to causal process becomes so complete that the concepts are no longer helpful in terms of critically engaging with the available evidence. Researchers look for ‘the elm decline’ because it has taken on an analytical, intellectual identity. Looking for ‘the elm decline’ or other comparable palaeoenvironmental events puts the interpretation before the data. Rather than characterizing the pattern of vegetation change at individual sample sites, seeking preconceived palaeoenvironmental responses starts to interpret data and applies a causal narrative prior to analysis. This is what Lowe and Higham (1998) referred to as ‘coherent myths’, and to which we will return later.

Archaeological questions

In Yorkshire and Humberside the latest Mesolithic activity has been identified on Pennine upland sites such as March Hill and South Haw (Spikins 2002; Griffiths 2014a and b). Looking at the earlier results, including those from North Gill 9, North Gill 4, Nosterfield SH1, Soyland D, Rishworth Moor, Langlands Farm, Gilderson Marr, Harwood Dale, Roos, and probably Lambwath Mere and the start of the decline at Newby Wiske (fig. 3), these signals could be indicative of temporary disturbances to the local vegetation including declines in elm of the sort noted by Albert and Innes (2015) at Esklets 1. This takes place when there is clear evidence in upland Yorkshire for late Mesolithic hunter-gatherer populations, including those returning repeatedly to what has been glossed as ‘persistent places’ (cf. Barton et al. 1995) such as March Hill. On this basis alone these pre-Neolithic disturbances could result in part at least from Mesolithic human-environment interactions.

The next evidence for elm declines in Yorkshire and Humberside is represented by a series of distributions centering on 3500 cal BC, after the first evidence for Neolithic material culture and practices in this region (Griffiths 2014b). The similarity of the estimates from Fen Bogs, North Gill 1A, North Gill 7, North Gill 5b, Bonfield Gill and Soyland C are notable; that for the elm decline at Esklets 4 is somewhat earlier, although this is described as “…a low scale event” (Albert and Innes, 2015, 370). The evidence for the decline at these sites thus occurs after the first evidence for Neolithic practices. This could be indicative of environmental disturbance associated with the wide ranging adoption of agriculture, post-dating as it does the timing of the appearance of cereals across Britain and Ireland (Griffiths in prep.) although none of these records are regarded as demonstrating clear palynological evidence for Neolithic clearance or farming (table 3). This said with the exception of Soyland C all these sites — Esklets, Bonfield Gill, and North Gill — are located in a relatively circumscribed area of the uplands of the North Yorkshire Moors. The similarity of these estimates, and that from Soyland C (a Pennine site), suggests that there might be some coherence in the post-Neolithic elm decline in the uplands of Yorkshire. It remains unclear how indicative these records are of wider environmental changes, especially given the relatively limited sample of lowland environments available within the region.

It has been suggested that the pollen record from Bonfield Gill indicates the use of fire to manipulate woodland structure during the Mesolithic, with disease potentially weakening trees subsequent to an episode of ‘forest farming’ during the earlier Neolithic (Innes et al. 2013). In this context, it is perhaps most telling that aside from Newby Wiske (Bridgland et al. 2011), none of the original interpretations of the pollen records unequivocally implicate human activity as a dominant factor, suggesting potentially highly complex processes which even detailed analytical approaches may not necessarily reveal (cf. Batchelor et al. 2013). Overall, if the elm decline was associated even in part with the impact of human activity it is clear that this process began prior to the introduction of farming in the study area. Later coherent signals for an elm decline from upland sites across Yorkshire may be associated with a geographical expansion of Neolithic practices into areas that were witness to the very latest Mesolithic practices.

Conclusion

This paper has provided new analysis of the timing of the elm decline in Yorkshire and Humberside, and compared this with evidence for Mesolithic and Neolithic material culture. We emphasize the importance of analyzing the available data, and variability in that data in order to develop critical chronologies. We suggest that the fine-grained chronologies offered by Bayesian modeling afford new opportunities for approaching human-environment interaction, and to explore the subtleties of these processes; 'noise' or variability in the timing and tempo of 'events' may actually be informing us about the nature of the underlying processes. We should not however assume that more precise chronologies, in and of themselves, will provide a catch all causal 'answer' if the models and approaches within which we frame our data are not sufficiently flexible.

In terms of the elm decline in Britain, without robust approaches to the chronology of latest Mesolithic and earliest Neolithic material culture and practices, understanding human involvement in these processes will inevitably be difficult, especially when people involved in Mesolithic and Neolithic lifeways might have been involved in complex human-environment interactions. Drilling down into the detailed evidence for environmental and anthropogenic change is essential to get beyond simple correlation:causation models. Without this, 'events' such as the elm decline risk taking on a mythic property (Lowe and Higham 1989), becoming what we might regard as chronological moveable causal feasts that are marshaled to cover insufficient data. We hope this paper demonstrates the inherent value in producing robust and quantifiable approaches to palaeoenvironmental chronologies. Noisy, complex data may be intrinsically interesting in terms of archaeological narratives; we are doing a disservice to our hard won evidence if we do not attempt to engage with this complexity.

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Table 1. Radiocarbon results associated with sites with indications for elm declines in the study area. The symbol * denotes that the information is not published.

Laboratory no.	Dated material, sample depth, association with elm decline, and reference.	14C age (BP)	δ 13 C (‰)
Esklets 1 (slight decline in elm apparent in sequence)			
Poz-38388	Peat, 60 cm deep. Albert and Innes 2015.	3625±35	*
SUERC-36700	Peat, 62 cm deep. Albert and Innes 2015.	3920±30	*
Poz-38389	Peat, 63 cm deep. Albert and Innes 2015. Depth of slight elm decline	5240±40	*
Poz-38390	Peat, 71 cm deep. Albert and Innes 2015.	6960±40	*
Beta-277101	Pinus wood, 77–8 cm deep. Albert and Innes 2015.	7670±60	*
Poz-38391	Peat, 84 cm deep. Albert and Innes 2015.	8150±50	*
Esklets 4 (elm decline apparent in sequence)			
Beta-277100	Betula wood, surface. Albert and Innes 2015.	4270±60	*
Poz-53595	Peat , 24.5 cm deep. Albert and Innes 2015. Depth of elm decline.	4780±35	*
Poz-36628	Peat , 30 cm deep. Albert and Innes 2015.	5210±40	*
Poz-39912	Pollen residue, 33.5 cm deep. Albert and Innes 2015.	6170±40	*
North Gill 1A (two elm declines apparent in sequence)			
SRR-3632	"bulk" peat (blanket deposits), 59cm deep, Turner et al. 1993; Simmons and Innes 1996c. Depth of elm decline 2.	3600±45	-28.1
SRR-3868 (humic)	Humic acid extract, 60cm deep, Turner et al. 1993; Simmons and Innes 1996c. Depth of elm decline 1.	4640±50	-29
SRR-3868 (humin)	Humin extract, 60cm deep, Turner et al. 1993; Simmons and Innes 1996c.	4650±90	-29
SRR-3633	"bulk" peat (blanket deposits), 72cm deep, Turner et al. 1993; Simmons and Innes 1996c.	3070±45	-28.4
SRR-3634	"bulk" peat (blanket deposits), 74cm deep, Turner et al. 1993; Simmons and Innes 1996c.	5515±45	-29.5
SRR-3869 (humic)	Humic acid extract, 75cm deep, Turner et al. 1993; Simmons and Innes 1996c.	5680±50	-28.8
SRR-3869 (humin)	Humin extract, 75cm deep, Turner et al. 1993; Simmons and Innes 1996c.	5465±170	-29
SRR-3635	"bulk" peat (blanket deposits), 79cm deep, Turner et al. 1993; Simmons and Innes 1996c.	5105±45	-27
North Gill 5b (elm decline apparent in sequence)			
HAR-6620	Peat; 30cm deep, Turner et al. 1993; depth of elm decline. Statistically consistent with SRR-3646.	4730±80	*
SRR-3646	"bulk" peat (blanket deposits); 30cm deep, Turner et al. 1993; depth of elm decline. Statistically consistent with HAR-6620.	4595±45	-27.6

Laboratory no.	Dated material, sample depth, association with elm decline, and reference.	14C age (BP)	δ 13 C (‰)
		Statistically consistent (T'%=2.2; T'5%=3.8; v=1) Weighted mean 4628±40	
SRR-3647	"bulk" peat (blanket deposits); 41cm deep, Turner et al. 1993. Statistically inconsistent with HAR-6619.	5240±45 4990±80 Statistically inconsistent measurements (T'=7.3; T'5%=3.8; v=1)	-27.6
HAR-6619	Peat; 41cm deep, Turner et al. 1993. Statistically inconsistent with SRR-3647.		*
SRR-3648	"bulk" peat (blanket deposits); 60cm deep, Turner et al. 1993 Statistically consistent with HAR-6616.	5540±45 5450±80 Statistically consistent (T'=1.0; T'5%=3.8; v=1) 5519±40	-28.7
HAR-6616	Peat; 60cm deep, Turner et al. 1993. Statistically inconsistent with SRR-3648.		*
HAR-6615	Peat; 73cm deep (NB dated using the miniature counter), Turner et al. 1993.	5760±90	*
North Gill 4 (elm decline apparent in sequence)			
SRR-3638	"bulk" peat (blanket deposits); 55cm deep, Turner et al. 1993; depth of elm decline.	5290±45	-28
SRR-3639	"bulk" peat (blanket deposits); 60cm deep, Turner et al. 1993	5335±45	-28.3
SRR-3640	"bulk" peat (blanket deposits); 63cm deep, Turner et al. 1993	5390±45	-28
SRR-3641	"bulk" peat (blanket deposits); 68cm deep, Turner et al. 1993	5250±45	-28.7
SRR-3642	"bulk" peat (blanket deposits); 69cm deep, Turner et al. 1993	5315±45	-28.4
SRR-3643	"bulk" peat (blanket deposits); 74cm deep, Turner et al. 1993	5405±45	-28
North Gill 6 (elm decline apparent in sequence)			
SRR-3649	"bulk" peat (blanket deposits); 74cm deep, Turner et al. 1993	3490±45	-27.7
SRR-3650	"bulk" peat (blanket deposits); 72cm deep, Turner et al. 1993	5220±45	-27.5
SRR-3651	"bulk" peat (blanket deposits); 58cm deep, Turner et al. 1993; depth of elm decline.	5515±45	-28.7
North Gill 7 (elm decline apparent in sequence)			
SRR-3653	"bulk" peat (blanket deposits); 69cm deep, Turner et al. 1993; depth of elm decline.	4625±45	-28.1
SRR-3654	"bulk" peat (blanket deposits); 72cm deep, Turner et al. 1993	4940±45	-29.6
SRR-3655	"bulk" peat (blanket deposits); 76cm deep, Turner et al. 1993	5645±45	-28.9
SRR-3656	"bulk" peat (blanket deposits); 80cm deep, Turner et al. 1993	6710±50	-28.3
SRR-3657	"bulk" peat (blanket deposits); 82cm deep, Turner et al. 1993	6735±45	-28.5

Laboratory no.	Dated material, sample depth, association with elm decline, and reference.	14C age (BP)	δ 13 C (‰)
North Gill 8 (elm decline apparent in sequence)			
SRR-3870 (humin)	Humic acid extract, 72cm deep, Turner et al. 1993; depth of elm decline.	3645±45	-28.2
SRR-3870 (humic)	Humin extract, 72cm deep, Turner et al. 1993; depth of elm decline.	3760±55	-28.3
SRR-3636	"bulk" peat (blanket deposits); 81cm deep, Turner et al. 1993.	5205±40	-29
SRR-3637	"bulk" peat (blanket deposits); 85cm deep, Turner et al. 1993.	5755±45	-28.8
North Gill 9 (two elm declines apparent in sequence)			
SRR-3871 (humin)	Humin extract, 67cm deep, Turner et al. 1993; depth of elm decline. Statistically consistent with humic acid fraction.	5690±45 5585±65 Statistically consistent (T'=1.8; T'5%=3.8; v=1) Weighted mean 5656±37	-28.3
SRR-3871 (humic)	Humic acid extract, 67cm deep, Turner et al. 1993; depth of elm decline. Statistically consistent with humin fraction.		-27.6
SRR-3872 (humin)	Humin extract, 68cm deep, Turner et al. 1993; depth of elm decline. Statistically consistent with humic acid fraction.	5670±105 5595±45 Statistically consistent (T'=0.4; T'5%=3.8; v=1) Weighted mean 5607±42	-28.5
SRR-3872 (humic)	Humic acid extract, 68cm deep, Turner et al. 1993; depth of elm decline. Statistically consistent with humin fraction.		-28
SRR-3652	“bulk" peat (blanket deposits); 80cm deep, Turner et al. 1993	6260±45	-29.1
Routh Quarry (suggested elm decline in sequence)			
AA-34124	"Bulk" peat; 55cm deep, Lillie and Gearey 2000; Gearey 2008; suggested elm decline.	3465±50	*
AA-34125	"Bulk" peat; 131cm deep, Lillie and Gearey 2000; Gearey 2008.	7575±65	*
AA-34126	H. nitens moss; 154cm deep, Lillie and Gearey 2000; Gearey 2008.	10740±75	*
AA-34127	H. nitens moss; 182cm deep, Lillie and Gearey 2000; Gearey 2008.	11260±75	*
AA-34128	"Bulk" peat; 201cm deep, Lillie and Gearey 2000; Gearey 2008.	11115±75	*
AA-34129	"Bulk" peat; 258cm deep, Lillie and Gearey 2000; Gearey 2008.	12595±80	*
Bonfield Gill (elm decline in sequence)			
HAR-4229	In situ tree root; 38–41cm deep, Simmons and Innes 1988c, Innes et al. 2013; depth of elm decline	4890±80	*
Wk-15150	Peat; 41cm deep, Simmons and Innes 1988c, Innes et al. 2013.	4418±42	*

Laboratory no.	Dated material, sample depth, association with elm decline, and reference.	14C age (BP)	δ 13 C (‰)
Wk-16273	Peat; 46cm deep, Simmons and Innes 1988c, Innes et al. 2013.	4644±43	*
HAR-4230	Peat; 45–50cm deep, Simmons and Innes 1988c, Innes et al. 2013.	4610±80	*
HAR-4226	Peat; 56–8cm deep, Simmons and Innes 1988c, Innes et al. 2013.	5170±90	*
Wk-15152	Peat; 75cm deep, Simmons and Innes 1988c, Innes et al. 2013.	5874±44	*
HAR-4255	Peat; 77–81cm deep, Simmons and Innes 1988c, Innes et al. 2013.	5670±90	*
Wk-15154	Peat; 83cm deep, Simmons and Innes 1988c, Innes et al. 2013.	6122±46	*
Wk-15151	Peat; 90cm deep, Simmons and Innes 1988c, Innes et al. 2013.	6187±47	*
Wk-15745	Peat; 99cm deep, Simmons and Innes 1988c, Innes et al. 2013.	6854±46	*
Gilderson Marr (elm decline present in sequence)			
AA-32310	Herb peat; 91–2cm deep, Tweddle 2000; Tweddle et al. 2005; depth of elm decline.	5445±75	-29.2
AA-32309	Herb peat; 137–8cm deep, Tweddle 2000; Tweddle et al. 2005.	7220±70	-29
AA-32311	Herb peat; 167–8cm deep, Tweddle 2000; Tweddle et al. 2005.	7785±105	-28.9
AA-32308	Herb peat; 183–4cm deep, Tweddle 2000; Tweddle et al. 2005.	8040±70	-28.3
AA-32307	Herb peat; 207–8cm deep, Tweddle 2000; Tweddle et al. 2005.	8140±70	-28.4
AA-32306	Herb peat; 239–40cm deep, Tweddle 2000; Tweddle et al. 2005.	8160±95	-28.7
AA-32305	Organic detrital mud; 267–8cm deep, Tweddle 2000; Tweddle et al. 2005.	8865±110	-31.7
AA-32304	Organic detrital mud; 297–8cm deep, Tweddle 2000; Tweddle et al. 2005.	9210±85	-31.3
AA-32303	Organic detrital mud; 317–8cm deep, Tweddle 2000; Tweddle et al. 2005.	9480±115	-32.8
AA-32302	Organic detrital mud; 341–2cm deep, Tweddle 2000; Tweddle et al. 2005.	9645±80	-33.7
Bluewath Beck (elm decline indicated at 95cm deep, not bracketed by radiocarbon measurements)			
Wk-12078	Charcoal-rich herbaceous peat; 141cm deep; Innes et al. 2010.	5879±40	
Wk-11597	Charcoal-rich herbaceous peat; 157cm deep; Innes et al. 2010.	6077±62	
Lambwath Mere (elm decline apparent in sequence)			
SRR-6537	Turfa peat; 57-62cm deep; Schofield and Bunting 2000.	1270±45	-29.1
SRR-6538	Tufa peat; 130-5cm deep; Schofield and Bunting 2000.	2100±50	-29.6
SRR-6539	Detritus peat; 222-7cm deep; Schofield and Bunting 2000.	3690±50	-28.9
SRR-6540	Gyttja; 323-8cm deep; Schofield and Bunting 2000; depth of elm decline.	5165±50	-30.3
SRR-6541	Gyttja; 469-74cm deep; Schofield and Bunting 2000.	7490±45	-29
SRR-6542	Gyttja; 630-5cm deep; Schofield and Bunting 2000.	9100±45	-29.6
SRR-6543	Gyttja; 775-80cm deep; Schofield and Bunting 2000.	9500±55	-30
The Bog at Roos (elm decline apparent in sequence)			
AA-32298	Herb peat with some Sphagnum; 49-50cm deep; Tweddle 2000; Tweddle et al. 2005.	870±50	-28.4
AA-32301	Herb peat with some Sphagnum; 78-9cm deep; Tweddle 2000; Tweddle et al. 2005.	1425±50	-28.2
AA-32297	Herb peat with some Sphagnum; 101-2cm deep; Tweddle 2000; Tweddle et al. 2005.	1720±50	-28.1
AA-32300	Herb peat with some Sphagnum; 132-3cm deep; Tweddle 2000; Tweddle et al. 2005.	2100±60	-28.4

Laboratory no.	Dated material, sample depth, association with elm decline, and reference.	14C age (BP)	δ 13 C (‰)
AA-32296	Herb peat with some Sphagnum; 153-4cm deep; Tweddle 2000; Tweddle et al. 2005.	2660±50	-28.2
AA-32295	Herb peat with some Sphagnum; 241-2cm deep; Tweddle 2000; Tweddle et al. 2005.	4400±80	-27.9
AA-32294	Herb peat with some Sphagnum; 275-6cm deep; Tweddle 2000; Tweddle et al. 2005.	4495±60	-27.3
AA-32293	Organic detrital mud; 317.5-8.5cm deep; Tweddle 2000; Tweddle et al. 2005; elm decline apparent in sequence.	5290±90	-34.3
AA-32292	Organic detrital mud; 379-80cm deep; Tweddle 2000; Tweddle et al. 2005.	7525±65	-33.2
AA-32299	Organic detrital mud; 434-5cm deep; Tweddle 2000; Tweddle et al. 2005.	7930±70	-30.6
AA-32291	Organic detrital mud; 494-5cm deep; Tweddle 2000; Tweddle et al. 2005.	8735±85	-28.3
AA-32290	Organic detrital mud; 549-50cm deep; Tweddle 2000; Tweddle et al. 2005.	9010±85	-29.8
AA-32289	Organic detrital mud; 583-4cm deep; Tweddle 2000; Tweddle et al. 2005.	9525±90	
AA-32288	Organic detrital mud; 607-8cm deep; Tweddle 2000; Tweddle et al. 2005.	1000±120	-34
Nosterfield SH1 (elm decline at the end of pollen zone SH1-b; Bridgland et al. 2011, 105)			
OxA-13012	Plant macrofossil; 495-6cm deep; Bridgland et al. 2011.	7705±34	-25.4
OxA-13104	Plant macrofossil; 338-40cm deep; Bridgland et al. 2011.	7435±39	-24.4
OxA-13225	OxA-13225 (Plant macrofossil) GrA-25048; 119-20cm; Bridgland et al. 2001. Statistically inconsistent (T'=13.69; T'5%=3.8; df=1; Ward and Wilson 1979).). OxA-13225 excluded from the analysis.	3427±35	-27.5
GrA-25048		3230±40	-30.1
GrA-24566	Plant macrofossil; 84-5cm deep; Bridgland et al. 2011.	2715±45	-30.0
Nosterfield F45 (start of deposition is terminus ante que for elm decline; Bridgland et al. 2001)			
Beta-143456	?	10180±60	
GrA-25355	Alnus sp. wood; 145cm deep; Bridgland et al. 2011.	4000±50	-27.1
OxA-13530	Charred twig; 128–9cm deep; Bridgland et al. 2011.	11675±50	-25.0
OxA-13553	Alnus sp. wood; 119–20cm; Bridgland et al. 2011.	4193±31	-27.1
OxA-13494	OxA-13494 bark, and GrA-25301 bark 93–4cm deep; Bridgland et al. 2011. Statistically consistent (T'2.2; T'5%=3.8; df=1; Ward and Wilson 1979). Weighted mean taken prior to calibration and modelling.	4124±30	-26.8
GrA-25301		4050±40 Weighted mean 4098±25	-27.4
GrA-25300	Bark; 41-2cm deep; Bridgland et al. 2011.	2395±35	-30.8
GrA-25299	Bark; 33-4cm deep; Bridgland et al. 2011.	2365±35	-30.2
OxA-13559	Plant macrofossils; 23-4cm deep; Bridgland et al. 2011.	2229±34	-26.7
OxA-13558	Plant macrofossils; 22-3cm deep; Bridgland et al. 2011.	2256±32	-26.3
Beta-143452	?	2330±40	
Nosterfield Sharow Mires (start of sequence terminus ante quem elm decline; Bridgland et al. 2011)			
SUERC-8881	Hazel nutshell; Bridgland et al. 2011.	7705±39	-25.4
Soyland C (elm decline apparent in sequence)			
Q-2385	Peat; 466-472cm deep; Williams 1985.	4565±50	

Laboratory no.	Dated material, sample depth, association with elm decline, and reference.	14C age (BP)	δ 13 C (‰)
Q-2386	Peat; 498-500cm deep; Williams 1985.	4865±50	
Q-2387	Peat; 538-543cm deep; Williams 1985.	6110±40	
Q-2388	Peat; 539-551cm deep; Williams 1985.	6340±50	
Q-2389	Peat; 578-585cm deep; Williams 1985.	6975±40	
Q-2390	Peat; 607-612cm deep; Williams 1985.	7640±40	
Q-2391	Peat; 632-638cm deep; Williams 1985.	8110±50	
Q-2392	Peat; 657-664cm deep; Williams 1985.	8650±75	
Soyland D (elm decline apparent in sequence; inferred in this work at 504 cm)			
Q-2393	Peat; 362-368cm deep; Williams 1985.	3400±100	
Q-2394	Peat; 497-503cm deep; Williams 1985.	5820±95	
Q-2395	Peat; 654-664cm deep; Williams 1985.	8650±75	
Rishworth Moor (elm decline apparent in sequence)			
Gak-2822	Peat; 180cm deep; Bartley 1975; depth of elm decline.	5490±140	
Gak-2823	Peat; 145cm deep; Bartley 1975.	4010±100	
Gak-2824	Peat; 100cm deep; Bartley 1975.	2420±100	
Gak-2825	Peat; 68cm deep; Bartley 1975.	1920±80	
Langlands Farm Nosterfield (terminus post quem for elm decline)			
GrA-24660	Alnus sp. wood; Bridgland et al. 2011.	5520±50	-28.8
Harwood Dale (elm decline apparent in sequence)			
HAR-5920	Peat; 240cm deep; Atherden 1989; depth of elm decline.	5310±80	
HAR-5919	Peat; 200cm deep; Atherden 1989.	4410±80	
HAR-5918	Peat; 160cm deep; Atherden 1989.	3910±80	
HAR-5917	Peat; 110cm deep; Atherden 1989.	2930±80	
HAR-5916	Peat; 70cm deep; Atherden 1989.	2190±90	
Gransmoor (elm decline apparent in sequence)			
SRR-229	Peat; 50-2cm deep; Beckett 1975.	5099±50	
Nosterfield Newby Wiske 1 (elm decline apparent in sequence)			
GrA-25030	Plant macrofossils; 355cm deep; Bridgland et al 2011.	1280±60	
OxA-13112	Plant macrofossils; 342cm deep; Bridgland et al 2011.	6710±50	
OxA-13107	Plant macrofossils; 215cm deep; Bridgland et al 2011.	8660±55	
OxA-13226	Plant macrofossils; 204cm deep; Bridgland et al 2011.	8265±45	
GrA-25028	Alnus sp. wood; 192cm deep; Bridgland et al 2011.	8040±50	
OxA-13322	Alnus sp. wood; 60-2cm deep; Bridgland et al 2011; start of elm decline	5241±32	
OxA-13321	Alnus sp. wood; 54-6cm deep; Bridgland et al 2011; end of elm decline	4921±33	
GrA-25031	Wood bark; 1-2cm deep; Bridgland et al 2011.	4315±40	

Laboratory no.	Dated material, sample depth, association with elm decline, and reference.	14C age (BP)	δ 13 C (‰)
Eshton Tarn (elm decline apparent in sequence)			
Birm-663	Peat; 218cm deep; Bartley et al. 1990; depth of elm decline.	5010±110	
Birm-662	Peat; 290cm deep; Bartley et al. 1990.	3600±100	
White Moss 1 (elm decline apparent in sequence)			
SRR-2487	Peat 583-7cm deep; Bartley et al. 1990.	7590±70	
SRR-2486	Peat; 523-7cm deep; Bartley et al. 1990.	6750±70	
Birm-665	Peat; 391cm deep; Bartley et al. 1990; depth of elm decline.	5080±100	
Birm-666	Peat; 167cm deep; Bartley et al. 1990.	1470±100	
Robinson's Moss (elm decline apparent in sequence)			
Q-2330	Peat; 403-10cm deep; Tallis and Switsur 1990.	8950±80	
Q-2321	Peat; 392-408cm deep; Tallis and Switsur 1990.	8775±90	
Q-2273	Peat; 362-70cm deep; Tallis and Switsur 1990.	7675±65	
Q-2434	Peat; 284-6cm deep; Tallis and Switsur 1990.	5470±50	
Q-2435	Peat; 265-7cm deep; Tallis and Switsur 1990; spanning elm decline.	4875±60	
Q-2436	Peat; 261-3cm deep; Tallis and Switsur 1990; above elm decline.	4710±50	
Fen Bogs (elm decline apparent in sequence)			
T1084	Peat; 632-35cm deep; Atherden 1976; depth of elm decline;	4720±90	
T1150	Peat; 475-81cm deep; Atherden 1976.	3400±90	
T1085	Peat; 257-5cm deep; Atherden 1976.	2280±90	
T1086	Peat; 160-3cm deep; Atherden 1976.	1530±130	
T1087	Peat; 113-6cm deep; Atherden 1976.	1060±160	
T151	Peat; 59-62cam deep; Atherden 1976.	390±100	

Table 2. Key posterior density estimates (in italics; see models in supplementary materials and figure 2) or calibrated radiocarbon dates calculated in this paper. All are quoted at 95% probability or confidence in years cal BC.

Parameter or radiocarbon measurement name	Date range (95% confidence or probability; cal BC)
Nosterfield SH1 elm decline	*5420-4350*
Soyland D elm decline	*5100-4490*
Bluewath Beck (Wk-12078) TPQ elm decline	4850-4610
North Gill 9 (SRR-3871) elm decline	*4530-4360*
North Gill 9 (SRR-3872) elm decline	*4550-4390*
Rishworth Moor (GaK-2822) elm decline	4610-3990
Langlands Farm (GrA-24600) TPQ elm decline	4460-4260
Gilderson Marr (AA-32310) elm decline	4450-4050
Harwood Dale (HAR-5920) elm decline	*4320-3970*
Roos (AA-32293) elm decline	4330-3960
North Gill 4 (SRR-3638) elm decline	*4225-3990*
Esklets 1 (Poz-38389) temporary elm decline	*4230-3960*
Lambwath Mere (SRR-6540) elm decline	4216-3790
Gransmoor (SRR-229) elm decline	3990-3770
Newby Wiske 1 (OxA-13322) start elm decline	*4160-3960*
Newby Wiske 1 (OxA-13321) end elm decline	*3920-3640*
Eshton Tarn (Birm-663) elm decline	*4050-3530*
White Moss (Birm-665) elm decline	*4040-3640*
Robinson's Moss (Q-2435) span elm decline	*3770-3520*
Esklets 4 (Poz-53595) elm decline	*3650-3380*
Fen Bogs elm decline	*3660-3100*
Bonfield Gill elm decline	*3520-3340*
North Gill 1A (SRR-3868) elm decline	3630-3340
North Gill 7 (SRR-3653) elm decline	*3620-3130*
North Gill 5b (SRR-3646) elm decline	*3530-3340*
Soyland C elm decline	*3520-3100*
Nosterfield F45 TAQ elm decline	*2900-2690*
Nosterfield Sharow Mires (SUERC-8881) TAQ elm decline	2480-2280
North Gill 8 (SRR-3870) elm decline	*2200-1970*
North Gill 6 (SRR-3649) elm decline	*1930-1690*
Routh Quarry (AA-34124) elm decline	1920-1650

Table 3. Summary of palynological signal and associated 'events' at *Ulmus* decline for sequences with chronological models relevant to period up to 3400 cal. BC (not including The Bog at Roos and Gilderson Marr). Note: Pollen percentage figures based on variable sums: North Gill sites (Turner *et al*. 1993) expressed as percentage TLP-*Corylus*, *Alnus* and *Salix*, except Esklets (%Arboreal pollen minus *Corylus*), Bluewath Beck (%Arboreal pollen minus *Corlyus* and *Alnus*), Robinson's Moss (% Arboreal Pollen), Gransmoor (%Arboreal pollen minus *Tilia*). Site references: Bonfield Gill (Simmons and Innes 1988, Innes *et al*. 2013), Bluewath Beck (Innes *et al*. 2013), Esklets (Albert and Innes 2015), North Gill Sites (Turner *et al*. 1993), Newby Wiske and Langland's Farm (Bridgland *et al*. 2011), Rishworth Moor (Bartley 1975), Robinsons Moss (Tallis and Switsur 1990), White Moss and Eshton Tarn (Bartley *et al.* 1990), Gransmoor (Beckett 1975).

Site/ sampling interval	**Elm decline depth**	***Ulmus* decline**	**Associated palynological 'events' at *Ulmus* decline**	***Ulmus* decline interpretation (original analysts)**
Bluewath Beck, 2cm	95cm	Steady, from c. 20% to c. 5% over 6cm	Increases in Poaceae, low vaues for *P. lanceolata* after UD, initial increases in other arboreal taxa. Fungal spores including *Kretzschmaria deusta* recorded	Attributed in part to early Neolithic anthropogenic activity following disturbance/burning during Mesolithic; fungal spores suggest dead wood possibly related to presence of dead/dying *Ulmus* perhaps due to ring barking/girdling
North Gill 9, 1cm	67-68cm	Abrupt over 1cm (from c.2-3 to 1-2%), but *Ulmus* falling steadily from 5cm below UD	Poaceae increases (c. 20 to 30%), *P. lanceolata* increases abruptly (c. 3-4%) after UD	UD at all North Gill sites attributed to impact of disease, with areas of trees possibly weakened/affected by Mesolithic human impacts
Rishworth, 5cm	180cm	Abrupt, from c. 10% to 4-5%	Slight increase in Poaceae, trace values for *P. lanceolata*, no other clear changes	Not discussed in detail although 'slight interference' in woodland proposed
Langland's Farm	65cm	Abrupt, c. 5% to 2-3%	Few other changes until above UD, steady increase in Poaceae, low values for *P. lanceolata* and other herbs	Only slight indications of anthropogenic activity around UD.
Harwood Dale, 10cm	240cm	*Ulmus* values low (c. 5%) before decline and increase c. 10cm above	Reduction in other trees at decline, slight rise in Poaceae, trace values of *P. lanceolata* and *Urtica*	Small scale human clearance follows UD
North Gill 4, 1cm	55-56cm	Abrupt over 1cm, *Ulmus* falls from c. 8% to c. 3-4%	Marked reduction in Poaceae (from c. 50% to c. 15%), increase in *P. lanceolata* (c. 2%) after UD	See North Gill 9
Esklets, E1, 1cm	Hiatus at 62cm	-	-	-
Newby Wiske 1, 2cm	61cm	Abrupt, c. 10% to less than c. 5%	Fall in *Tilia*, appearance of cereal-type and increase in *P. lanceolata,* spores of *Kretzschmaria deusta*	Anthropogenic clearance for agriculture suggested.

			recorded	
Eshton Tarn, variable, 2cm across decline	218cm	Abrupt, *Ulmus* drops from c. 5% to trace values	Reduction in Poaceae, decrease in *Quercus* and *Corylus*, increase in *Alnus*, *P. lanceolata* appears before UD	Disease vector' implicated at Eshton and White Moss on basis of chronological correlation although evidence for 'interference in forest and establishment of grazing land' before UD at both sites
White Moss 1, variable 2cm across decline	400cm	*Ulmus* begins to fall from c. 5% before recognised decline, c. 1-2% after	Increases in Poaceae, isolated peak in *P. lanceolata* at UD	See above
Robinsons Moss, variable, 1cm across decline	266cm	Abrupt, from c. 10% to c. 2-3%	No clear changes in other taxa	Evidence for Pre UD impact on vegetation including burning, but human impact not linked to UD; disease proposed following weakening of populations due to environmental stress
Esklets, E4, 1mm	24.5cm	Not pronounced, *Ulmus* remaining at c. 4-5%	No clear changes, although ruderal pollen present, dung fungi may reflect grazing/stock herding	Evidence for Mesolithic impacts in both records, Esklets 4 – decline is ephemeral, no evidence for significant clearance of woodland
Fen Bogs, 10cm	620cm	Abrupt fall in *Ulmus* from c.5% to <1%	Reduction in *Tilia* at decline, Poaceae increases after decline, trace values for *P. lanceolata*	Small scale human impacts suggested pre UD, UD not considered in depth
Bonfield Gill, 2cm	42-44cm	Abrupt over 2cm, *Ulmus* falls from c. 20% to low values)	Increase in Poaceae, low (c. 1%) and sporadic increases in *P. lanceolata* after UD	See North Gill 9
North Gill 1A, 1cm	59-60 cm	Abrupt over 1cm, *Ulmus* falls from 10% to c. 2%	Marked increase in *Calluna*, decrease in Poaceae, *P. lanceolata* increases (1%) after UD: probable hiatus	See North Gill 9
North Gill 7, 1cm	69-70cm	Steady fall (c. 10% to 5%) from 70cm to 66cm	Fall in Poaceae after decline (c. 70% to 25%), *P. lanceolata* appears at low values (c. 1%) above decline	See North Gill 9
North Gill 5b, 1cm	30-32cm	Steady, 32-28cm, *Ulmus* falls from 8% to 1-2%	Marked increase in Poaceae (c. 45 to 70%), *P. lanceolata* steady rise (c. 3-4%) above UD after 29cm	See North Gill 9
Soyland Moor C	470cm	Steady fall		Upland site, possible comparisons with the North Yorkshire Moor evidence.

Soyland D	504cm	Steady fall		Decline unclear; suggested at 370cm interpreted here at 504cm.
Gransmoor, 0.04m	0.88m	Abrupt over 0.04m, *Ulmus* falls from 5-10% to c. 1%	No clear increases in herbs; rise in other trees after decline including *Alnus* and *Tilia* remaining dominant, the latter swamps pollen record (excluded from sum)	Possible anthropogenic cause.